Natural and Accelerated Bioremediation Research
Field Research Centers
Strategic Plan

Office of Biological and Environmental Research
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1.0 Introduction

The Natural and Accelerated Bioremediation Research (NABIR) Program is an interdisciplinary, basic research program in the Environmental Remediation Sciences Division (ERSD) in the Office of Biological and Environmental Research (BER) in the Department of Energy's (DOE's) Office of Science. The goal of the NABIR program is to provide a fundamental science basis for the development of cost-effective strategies for microbial bioremediation of radionuclides and metals in the subsurface at DOE sites.

The focus of the NABIR program is on radionuclides and metals that are of concern at DOE sites and are tractable to bioremediation. Thus, research is focused on the metals chromium and mercury, and on the radionuclides uranium, technetium and plutonium. NABIR research is oriented toward application in areas that have low levels of widespread contamination in the subsurface below the zone of root influence, and includes both the unsaturated (vadose) zone and the saturated (ground water) zone.

NABIR research encompasses intrinsic bioremediation by naturally occurring microbial communities, as well as accelerated bioremediation through biostimulation (addition of inorganic or organic nutrients) or, if necessary, bioaugmentation (additions of microorganisms). Strategies leading to the immobilization of contaminants in place are of primary interest.

To encourage hypothesis-based field research and process-level understanding, the NABIR program has established the Field Research Center (FRC) concept for long-term field studies. The FRC provides a location on a DOE site where scientists can conduct field-scale research and obtain DOE-relevant subsurface samples for laboratory-based studies of bioremediation. Currently, there is a single Field Research Center (FRC) located on DOE's Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee. Staff from Oak Ridge National Laboratory's Environmental Sciences Division have operated the FRC since April 2000.

Field-scale, hypothesis-based research at the Oak Ridge FRC can be undertaken at a contaminated and/or an uncontaminated control area. Both the contaminated and uncontaminated areas are located on the ORR's Y-12 National Security Complex in Bear Creek Valley. These areas are underlain by shales, siltstones, and limestones of the Conasauga Group. The contaminated area includes commingled ground water plumes that originated from a combination of the S-3 Waste Disposal Ponds and the Bone Yard/Burn Yard. The primary contaminants are uranium, nitrate, technetium, strontium, and cadmium. Other metals such as mercury, copper, zinc, and lead, and organics such as acetone, methylene chloride, tetrachloroethylene, and toluene, are also present. Both the uncontaminated and contaminated areas are well characterized, well instrumented, and are expected to be available for 5 to 10 years. The water table resides 0 to 3 meters below the surface and is readily accessible to instrumentation of the ground water monitoring wells. Additional details on the geology and hydrology of the Oak Ridge FRC can be found at: http://www.esd.ornl.gov/nabirfrc/.

The initial focus of *in situ* research at the Oak Ridge FRC by NABIR investigators has been on *in situ* biostimulation experiments to promote the immobilization of uranium and technetium. Understanding the mechanisms controlling natural and stimulated uranium biotransformation in the presence of high nitrate in heterogeneous, unconsolidated residuum where both fracture flow and matrix diffusion occur are major challenges at the FRC, and at other DOE sites with similar hydrogeologic characteristics. Three research projects are underway at the Oak Ridge FRC to address *in situ* immobilization of uranium in the presence of high nitrate. Briefly, the three field projects include 1) a stimulated biocurtain for uranium biotransformation combined with denitrification, 2) push-pull tests to determine the kinetics of electron-acceptor and electron-donor use for microbially mediated uranium and technetium reduction and reoxidation, and 3) stimulation of microbial uranium reduction in hydrologically-accessible fractured zones to precipitate uranium oxide and isolate the uranium in low-permeability porous regions. For detailed descriptions of these three projects, see http://www.lbl.gov/nabir/fieldresearch/frc/index.html.)

Although the Oak Ridge FRC was established for long-term field studies by NABIR investigators, some investigators from other programs within the ERSD may be able to make use of the FRC. Specifically, some investigators from the Environmental Management Sciences Program (EMSP) may be able to make use of the FRC. The EMSP funds basic research projects across a wide spectrum of topics related to environmental remediation and waste management, including high-level nuclear waste, characterization and processing, decontamination and decommissioning, health, ecological risk assessment and characterization and remediation of subsurface contamination in the vadose and saturated zones. Because many of the topics being studied by EMSP researchers bear directly on the fate and transport of metals and radionuclides in the subsurface, the results of these EMSP investigations also have the potential to advance the goals of the NABIR Program. Field-based research opportunities for EMSP investigators at the FRC might include fate and transport studies, tests of subsurface characterization and monitoring methods, tests of barriers and other non-biological immobilization methods and studies of organic or mixed metal/organic contamination.

In October 2001, the NABIR subcommittee of the Biological and Environmental Research Advisory Committee (BERAC) reviewed both the research activities and the operational aspects of the Oak Ridge FRC. One recommendation from this review was to develop a "brief scientific strategy…that builds on the unique properties of the site and aids in establishing research priorities and directions consistent with the NABIR Strategic Plan." This FRC strategic plan responds to the subcommittee's recommendation, and identifies ways to expand the utility of the existing and future FRCs to encompass other ERSD programs.

2.0 Field Research Centers Mission

The mission of the existing Field Research Center (FRC) and any future FRCs is:

> **To serve as premier field research sites at which NABIR and other BER investigators can obtain samples and conduct *in situ* studies that will lead to new insights into the bioremediation of metals and radionuclides and related contaminant fate and transport processes.**

3.0 Field Research Centers Goals

This document presents a ten-year Strategic Plan for the FRCs, consistent with the overall NABIR Program Plan. Fulfilling the mission of the FRCs will require a coordinated set of goals. The four goals for the FRCs are:

> *1) To operate effectively as major field-scale research facilities for NABIR and other investigators, by offering a multitude of opportunities for testing scientific hypotheses concerning the* in situ *bioremediation of toxic metals and radionuclides.*
>
> *2) To serve as a resource for advancing the scientific understanding of the fundamental mechanisms of microbially-mediated metal and radionuclide immobilization, for advancing subsurface characterization and monitoring technologies, for developing a predictive capability for bioremediation, and for providing an in depth understanding of the fate and transport of contaminants in the subsurface.*
>
> *3) To integrate and coordinate field research within the NABIR Program, to integrate relevant research within other BER programs such as EMSP and Genomes to Life (GTL), and to coordinate FRC research with research being managed by other federal programs and organizations, where appropriate and beneficial.*
>
> *4) To provide educational opportunities for students and to provide collective scientific and site characterization data and research findings on a regular basis to the scientific community, regulators, end-users and other stakeholders.*

To make systematic progress toward each of the four goals, a series of tasks have been developed for each goal. While some of these tasks will occur throughout the decade, others will predominate during specific phases of this ten-year plan. Short-term tasks will occur in years 1-3, middle-term tasks will occur in years 4-6 and long-term tasks will occur in years 7-10. The following sections are organized according to goal and according to the tasks that will predominate during the different timeframes. An overview of the tasks proposed in this strategic plan as a function of time is provided in Appendix I.

3.1 Goal 1 - Operating FRCs Effectively

Effective operation of major field-scale research facilities that benefit NABIR and other BER investigators will require sustained, coordinated efforts by the NABIR Program Managers, the FRC Manager and staff, the Field Research Review Panel and NABIR investigators.

The NABIR Field Activities Manager at DOE is responsible for coordinating, reviewing and funding: 1) the overall activities at the FRC and 2) individual NABIR investigators conducting *in situ* research projects at the FRC. Other NABIR Program Managers at DOE are responsible for coordinating, reviewing and funding other individual NABIR investigator projects, some of which may use FRC resources (*e.g.*, samples).

The FRC Manager at the FRC is responsible for the overall management of the FRC operations and budget, including physical logistics of the site, coordination of users, interactions with regulators and other on-site contractors, field site characterization, *etc.* The FRC Science Advisor provides scientific advice to the FRC Manager and serves to coordinate research involving FRC samples and *in situ* activities.

To ensure that proposed *in situ* research and characterization activities are fully planned and coordinated, an independent Field Research Review Panel (FRRP) reviews: a) detailed work plans submitted by scientists planning to conduct *in situ* research at an FRC field site, and b) field site characterization efforts planned by the FRC Manager, and responds to the FRC Manager with recommendations to improve the planned research and/or characterization activities.

3.1.1 Core Operational Activities

Core operational activities are those activities that are needed to keep an FRC operating effectively. Some of these core operational activities may evolve as the *in situ* research at the FRCs changes over time, especially as non-NABIR investigators make greater use of the FRCs, and as a second FRC is developed.

The NABIR Field Activities Manager will:

- Ensure that field-scale activities are linked to the goals of the NABIR Strategic Plan a) through focused basic research efforts designed to enhance fundamental knowledge on the microbially-mediated *in situ* immobilization of contaminants, and b) by promoting the development and testing of tools and techniques for field or laboratory analysis and monitoring.
- Focus *in situ* multi-disciplinary research on large-scale, subsurface contamination issues to resolve problems that were once considered intractable.
- Promote linkages and data dissemination among DOE programs (*e.g.*, EMSP and Genomes to Life - GTL) and other federal agencies to maximize the success of multi-investigator, multi-institution efforts.
- Encourage synergism of investigations and operational activities between the FRCs.

The FRC Manager will:

- Operate and manage the FRCs as customer-oriented user facilities that are committed to DOE's mission of managing and operating its facilities in a safe and environmentally responsible manner.
- Establish and maintain management and operational procedures and associated documentation for the FRC*.
- Establish field plots and conduct baseline geochemical and hydrologic characterization sufficient for investigators to plan detailed characterization studies and *in situ* research.
- Disseminate data from site characterization studies to scientists to support-hypothesis-based research.
- Provide state-of-the-art equipment and knowledgeable support staff to quantify key field-scale hydrological, geochemical, and microbiological processes.
- Distribute ground water, sediment/soil, core and other relevant environmental samples to investigators.
- Maintain a data management system that provides scientists with characterization data through a web-based data retrieval system.
- Assist the NABIR Field Activities Manager in transferring knowledge and technologies to EM's performance/risk assessment and decision-making process for DOE site restoration.
- Publish and distribute a periodic newsletter to NABIR and other interested scientists that provides a) updates on preliminary results from *in situ* studies and recently completed characterization and operational activities and b) a description of future plans for additional activities at or by the FRC.

The FRC Science Advisor will:

- Provide science/technical support to the FRC Manager on the latest techniques and findings that can be applied at the FRC, and based on that information, suggest new directions for ongoing and future studies.
- Establish and coordinate working groups in pertinent research areas so that coordination and data sharing can be tightly linked within and between groups of investigators working at the FRC and with FRC samples.
- Periodically analyze the extent to which NABIR research, whether conducted in the field or in laboratories using site samples, is coordinated and linked, and recommend methods for improving that coordination to the FRC Manager.
- Assist the FRC Manager in planning and hosting an annual FRC users meeting.

* Further detail on the operational plans and procedures for each FRC will be contained in an FRC Management Plan, Site Characterization Plan, Quality Assurance Plan, and Health and Safety Plan and other documentation. For the Oak Ridge FRC, these plans are accessible at http://public.ornl.gov/nabirfrc/frcdoc.cfm.

The FRRP will independently review work plans for *in situ* research from individual NABIR investigators, and field site characterization plans from the FRC Manager, and respond with recommendations to the FRC Manager concerning the:

- Feasibility of planned field research and characterization activities at the FRC, including whether studies are planned to minimize environmental impacts.
- Degree to which proposed or continuing field studies may impinge upon the usability of field sites for research by NABIR or other investigators, considering potential adverse effects on 1) studies already underway, 2) potential future studies, 3) regulatory implications and 4) resources.

3.1.2 Short-Term Operational Tasks (1-3 Years)

Operational tasks to be undertaken in the short-term include:

- **Identify and characterize existing and new field plots at the Oak Ridge FRC:**
    - Identify, conduct baseline geochemical and hydrologic characterization, and make available to investigators new field plots further west of the S-3 Ponds parking lot than those that currently exist, as well as new field plots east of the S-3 Ponds parking lot. (Because the S-3 Ponds parking lot resides on a ground water divide, the characteristics of the ground water plumes on the two sides of the parking lot may differ.)
    - Further characterize the existing uncontaminated and contaminated areas at the Oak Ridge FRC. Additional characterization is needed to enable NABIR and non-NABIR investigators to design *in situ* studies and to begin to develop an understanding of conditions and processes important for microbial immobilization of the contaminants.

- **Identify and establish a new FRC at a DOE site where the subsurface hydrogeology differs substantially from that at the Oak Ridge FRC (*e.g.*, granular porous media *vs.* humid, fractured saprolite), but where the contaminants are similar in type and concentration.** A DOE site with a different hydrogeology from that at the Oak Ridge FRC will allow NABIR and other scientists to study fundamental bioremediation and fate and transport processes in very different subsurface environments. Having two FRCs at two different DOE sites with different hydrogeology will help the NABIR Program and other ERSD programs in transferring research results to DOE sites for use in developing cleanup strategies. DOE will undertake a solicitation and review process that leads to the selection of a new FRC. By the end of the short-term, DOE expects to initiate operations at the new FRC.

- **Open the Oak Ridge FRC to non-NABIR investigators, especially EMSP and GTL investigators in accordance with the interests of ERSD to make more DOE field sites available for *in situ* research (see Section 3.3, "Integrating and Coordinating," for additional discussion).**

3.1.3 Middle-Term Operational Tasks (4-6 Years)

Middle-term operational tasks include:

- **Continue to expand the number and extent of hydrologic and geochemical characterization of the field plots available for investigators at the Oak Ridge FRC so that more *in situ* studies can be accommodated.** The extent to which the Oak Ridge FRC field plots could be expanded further west along Bear Creek Valley will be determined by conducting exploratory field characterization studies to identify the types and concentrations of contaminants in the Maynardville Limestone associated with the Boneyard/Burnyard (BY/BY).

- **Install boreholes and injection wells at the second FRC for *in situ* research by NABIR investigators and investigators from other programs.** NABIR and/or other investigators will begin receiving samples from and will initiate *in situ* studies at the second FRC.

- **Increase coordination among the FRC staff, PI's and DOE to ensure that operation of two FRCs for multiple programs is efficient.** Examples include development of common Quality Assurance/Quality Control standards and outreach and communication mechanisms or tools, and regular coordination meetings or conference calls. See Section 3.3.2 for additional details.

3.1.4 Long-Term Operational Tasks (7-10 Years)

The long-term operational tasks include:

- **Continue site operations, characterization and expansion for any existing and new FRCs.** In addition, continue efforts to coordinate between the FRCs.

3.2 Goal 2 - Advancing Scientific Understanding and Analytical and Predictive Capabilities

The second goal for the FRCs builds on the objectives and R&D targets identified in the 2001 Strategic Plan for the NABIR Program (http://www.lbl.gov/NABIR/). The NABIR program is comprised of four Science Elements: Biogeochemistry, Biotransformation, Community Dynamics/Microbial Ecology, and Biomolecular Science and Engineering. In addition, there is a crosscutting Science Element called Assessment that encourages the development of new tools and approaches to achieve the goals of the program. A detailed description of the objectives and R&D targets for each of these elements can be found in the NABIR Strategic Plan. As stated in that document, the Oak Ridge FRC provides a site for investigators to conduct field scale research and to obtain DOE-relevant subsurface samples for laboratory-based studies of bioremediation. It is also anticipated that future coordination between NABIR and EMSP researchers at the Oak Ridge and at a second FRC will lead to an improved understanding of the fate and

transport of contaminants in a range of hydrogeologic settings, which will help refine predictive model capabilities.

The short-, middle-, and long-term scientific tasks for this goal are designed to investigate increasingly complex issues associated with bioremediation and related processes. The tasks are not meant to be exclusive, but rather represent a shift in focus over time. The short-term scientific tasks focus on understanding the existing field site conditions and the basic processes involved in biostimulation to achieve uranium and/or technetium immobilization. The middle-term tasks emphasize research that leads to improved parameters for modeling the fate and transport of uranium and/or technetium, and for understanding bioremediation in the context of overall fate and transport. The long-term scientific tasks focus on enhancing the understanding of the strengths and limitations of microbially-mediated subsurface metal and radionuclide remediation in mixed contaminant situations and in different environments (*i.e.*, at different FRCs). The results of these efforts are expected to provide a valuable information base for any subsequent demonstration and deployment projects.

In addition to the transition from research on the basic processes to interactions among the processes, the scale of investigation at the field sites will change over time. Studies will focus on the meter scale in the short-term, tens of meters in the middle-term, and larger-scale plumes in the long-term.

3.2.1 Short-Term Scientific Tasks (1-3 Years)

In the short-term, scientific tasks at the Oak Ridge FRC primarily will focus on understanding the existing field site conditions and the basic processes involved in biostimulation to achieve uranium and/or technetium immobilization. These short-term tasks largely will be conducted by the FRC or by NABIR investigators. However, some EMSP and GTL investigators are expected to obtain samples from the Oak Ridge FRC in the short-term. Short-term scientific tasks are not identified for the second FRC because *in situ* investigations are not likely to begin at this site during the next 1-3 years. Specific short-term scientific tasks for the Oak Ridge FRC include:

- **Achieve uranium and/or technetium immobilization in the field at the Oak Ridge FRC.** Although immobilization of metals and radionuclides has been demonstrated in laboratory settings, the ability to replicate those findings under field conditions has been limited to a few select cases. Initial *in situ* studies by NABIR-funded investigators are focusing on whether, and under what conditions, immobilization of metals and radionuclides is possible.* In general, these studies are, and will continue to be focused on hydrologic, geophysical, geochemical and/or microbiological conditions and processes involved in natural attenuation and biostimulation.

* Initial *in situ* studies at the FRC by NABIR scientists suggest that immobilization can be achieved under field conditions.

- **Undertake additional site characterization at the Oak Ridge FRC in support of *in situ* studies.** Because multi-scale geologic heterogeneity (*e.g.*, variations in hydrologic parameters or mineralogy), and perhaps microbial heterogeneity may exert a strong influence on contaminant transport and the efficacy of bioremediation, characterizing this heterogeneity will be an important component for planning the field-scale experiments and for understanding the results. Characterization efforts either by the FRC staff or by NABIR or other investigators may include: 1) analyses of microbial community structure and function within the saturated and vadose zones in the presence of multiple mixed contaminant situations, 2) characterizing site permeability at different scales, 3) developing a greater understanding of core microbiology and geochemistry, 4) discerning the relationships between solid phase mineralogy and contaminant speciation, 5) using high-resolution spectroscopic techniques to determine contaminant species in aqueous and solid phases and 6) using high-resolution geophysical methods to estimate the hydrogeological heterogeneity and to remotely monitor subsurface transformations during field-scale experiments. Many of these topics are being actively studied by EMSP researchers, thus there may be good opportunities for collaborative projects that will benefit both the EMSP and NABIR programs.

- **Identify the conditions and processes at the Oak Ridge FRC that may be important for microbial reduction within a plume.** Part of the challenge of field research is to understand the myriad of conditions and processes that, singly and in combination, are relevant to the efficacy of *in situ* bioremediation. Therefore, *in situ* studies conducted in the short-term may begin to identify potentially important field conditions and processes, such as those affecting contaminant transport and microbial oxidation/reduction, at a relatively small field scale (such as a meter.) Other possible realms of investigation include: a) preferred contaminant discharge pathways along geologic strike, b) changes in geochemical and microbial gradients with increasing distance from the source and c) natural attenuation processes down gradient from the contaminant source.

- **Develop a conceptual model of the Oak Ridge FRC.** To help investigators focus their field studies on important hydrologic, geophysical, geochemical, and microbial processes, a more detailed conceptual model of the contaminated area of the Oak Ridge FRC will be developed by the FRC. This task will be the responsibility of the FRC Science Advisor in consultation with the FRC Manager and investigators. The conceptual model will correlate data from previous site studies with data from continuing NABIR investigator studies. It will provide a 3D visual with point-and-click capability for data access, and will be made available for use by NABIR investigators and others. The Oak Ridge FRC conceptual model will be updated periodically to incorporate new information from FRC investigations. Further, the model will serve (a) to integrate NABIR research activities at the Oak Ridge FRC and (b) as a basis for communication about NABIR science with other investigators, end-users, and stakeholders. Because individual investigators may develop models specific to their field plot, there will be a need for integration with the conceptual model. This will be an issue that is handled by a numerical modeling "working

group." Further details on this and other working groups are contained in Section 3.3.1.

3.2.2 Middle-Term Scientific Tasks (4-6 Years)

Middle-term scientific tasks will be oriented toward research that leads to improved parameters for modeling the fate and transport of uranium and/or technetium, and for understanding bioremediation in the context of the overall fate and transport of contaminants. The middle-term tasks are expected to encompass activities at both the Oak Ridge FRC and at a second FRC. Collaborations between NABIR, EMSP and GTL investigators are expected to enhance the overall impact of research results provided by these programs. The middle-term scientific tasks include:

- **Improve the understanding of conditions and processes that promote or inhibit *in situ* bioremediation of metals and radionuclides.** The scale of field endeavors will tend to increase from meters to the tens of meters scales, thereby capturing new phenomena and processes relevant to *in situ* bioremediation. Topics that may be investigated by NABIR, EMSP and GTL investigators at the Oak Ridge FRC include preferential flow pathways, importance of storm events and seasonal changes in the capillary fringe and buffering of contaminant plumes due to the solid phase.

- **Identify and characterize candidate field plots for *in situ* studies of other redox-sensitive metal contaminants at the Oak Ridge FRC.** Because of the mixture of contaminants at the Oak Ridge FRC, there may be opportunities for NABIR and other BER investigators to undertake studies of other redox-sensitive metals such as chromium and mercury.

- **Revise the Oak Ridge FRC conceptual model.** Information based on research conducted and published by NABIR and other investigators will be incorporated into the conceptual model. Modeling will focus on improving the linkage of multidisciplinary experimental data with existing multi-process biogeochemical transport models. Modeling activities may include the use of high-performance computers to validate existing geochemical or flow and transport models based on FRC experimental data, incorporating multi-scale experimental datasets from NABIR studies into local codes, and modeling contaminant mobility during transient storm events in high recharge regions. Based on new model outputs, additional studies within NABIR and by other investigators will be initiated.

- **Initiate new *in situ* research studies and begin to develop conceptual model at the second FRC.** NABIR and other investigators will undertake *in situ* studies at selected field plots at the second FRC and use resulting information to begin to develop a conceptual model of subsurface processes at the second FRC field site(s).

3.2.3 Long-Term Scientific Tasks (7-10 Years)

The long-term scientific tasks will be oriented at increasing the understanding of the strengths and limitations of microbially-mediated subsurface metal and radionuclide remediation in mixed contaminant situations and in different environments (*i.e.*, at different FRCs). The long-term tasks will encompass activities at both the Oak Ridge FRC and at a second FRC, and may include:

- **Develop a comprehensive understanding of metal and radionuclide plumes at the Oak Ridge FRC.** Through the use of the scientific results from the short- and middle-terms, investigators will have an improved scientific understanding of the degree to which natural or accelerated bioremediation can be used to treat subsurface plumes of metals and radionculides. In addition, the knowledge base of fundamental coupled processes that control the biogeochemistry of metals and radionuclides *in situ* should allow predictions at the plume scale.

- **Continue *in situ* studies at the second FRC with a focus on increasing length scales of investigation.** Efforts may focus on comparative studies using data collected from both FRCs to understand the influence of site-specific conditions on bioremediation results.

- **Enhance modeling and visualization tools.** Network-based visualization and modeling interfaces will be developed by the FRC for real-time visualization and simulation of FRC field studies and steering of experimental design and results. Monitoring and predictive models for long-term (hundreds of years) natural attenuation and more active bioremediation strategies will be developed.

- **Revise conceptual models to use predictive capabilities.** Information based on research conducted and published by NABIR investigators will be incorporated into the conceptual models for both the Oak Ridge FRC and the second FRC. Based on outputs from the new model, new studies by NABIR and by other investigators likely will be proposed.

3.3 Goal 3 - Integrating and Coordinating within NABIR and with Other BER Programs

Ensuring that research conducted by NABIR and other scientists at the FRCs, or with FRC samples, is tightly integrated will be a continuing activity throughout the life of the FRCs. As described in the following short-, middle- and long-term tasks, the NABIR Field Activities Manager, the FRC Manager, the FRC Science Advisor and the FRRP will all play key roles in integrating and coordinating research activities at the FRCs.

3.3.1 Short-Term Integration Tasks (1-3 Years)

The short-term integration tasks include:

- **Schedule quarterly conference calls that involve the NABIR Field Activities Manager, the Oak Ridge FRC Manager, the Oak Ridge FRC Science Advisor and the lead NABIR scientists conducting *in situ* research at the Oak Ridge FRC.** The purpose of these quarterly conference calls will be to ensure that progress is being made and that activities among the *in situ* projects are being coordinated so that activities associated with one project do not compromise activities or results from a second project at the same field site.

- **Review all work plans for *in situ* research at the Oak Ridge FRC as well as any field site characterization activities prior to initiation.** As part of its charter, the FRRP is charged with reviewing *in situ* work plans to ensure that the planned work does not interfere with existing *in situ* research or on the future usability of field sites. The existence of the FRRP and their review process will continue throughout the life of the Oak Ridge FRC. Once a second FRC is selected, a FRRP review process will be established for the second FRC.

- **Review and analyze the extent of coordination and integration at the FRC between NABIR and other researchers, and establish working groups to promote integration.** As stated under the core activities of the FRC Science Advisor in Section 3.1.1, the FRC Science Advisor will perform this periodic analysis and will lead efforts to establish and oversee the activities of FRC research "working groups" focused on specific topics. Working groups will be formed around the following topics: 1) microbial community analysis, 2) geochemical/geophysical characterization/monitoring, 3) rates and mechanisms of microbially-mediated metal reduction and 4) numerical modeling, The lead individual for each working group will coordinate with the FRC Science Advisor to: a) identify how the FRC can best be used to address specific research needs, b) help delineate the extent and types (*e.g.*, geophysical methods) of field site characterization for a specific field plot that should be performed by the FRC *vs.* that by an individual investigator/research team, c) help delineate the extent of post-experimental monitoring that should be performed by an individual investigator/research team *vs.* that by the FRC, d) identify opportunities for cross-disciplinary interaction and e) help integrate interested and newly funded NABIR and other scientists at the FRC.

- **Integrate the lessons learned from operational planning activities associated with other NABIR field studies, especially results from *in situ* NABIR research at Uranium Mill Tailings Remedial Action (UMTRA) sites.** A number of NABIR investigators are conducting *in situ* research at several UMTRA sites. As with all field experiments, extensive operational planning is required prior to, during, and after these *in situ* studies are completed. Knowledge of these planning activities and the findings from these *in situ* studies may be useful to the FRC Manager(s). The

FRC Manager(s) will be asked to participate in coordination meetings and conference calls associated with *in situ* studies at UMTRA sites.

- **Open the Oak Ridge FRC to BER-funded investigators, especially EMSP and GTL investigators.** In the short-term, both EMSP and GTL investigators may only want to receive ground water, sediment/soil or core samples from the Oak Ridge FRC. As the Oak Ridge FRC Manager identifies field plots available for EMSP or GTL investigations, those plots will be made available in the middle-term to those investigators. Collaborations between EMSP or GTL and NABIR investigators will be encouraged by DOE, and field plots may be identified by the FRC Manager for collaborative *in situ* research.

- **Seek opportunities to coordinate and enhance links with such non-DOE federal programs and agencies as National Science Foundation (NSF), the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), the Strategic Environmental Research and Development Program (SERDP), and others.** This task will be the responsibility of the NABIR Field Activities Manager and the FRC Manager.

3.3.2 Middle-Term Integration Tasks (4-6 Years)

The middle-term integration tasks include:

- **Increase coordination and integration among NABIR studies and other BER programs at the Oak Ridge FRC.** As the number of active projects increase, integration among NABIR, EMSP and GTL projects will increase considerably, and the number of participants on the quarterly conference calls will expand. Non-NABIR activities at the Oak Ridge FRC may take several forms: obtaining samples, collaborating with NABIR investigators and/or conducting investigations at existing or new field plots. Balancing the use of the Oak Ridge FRC by NABIR and non-NABIR investigators for sampling and *in situ* research will require much coordination with, and additional resources from, the other programs. While investigators from other DOE programs will be encouraged to coordinate with NABIR investigators on studies such as the fate and transport of metals and radionuclides, non-NABIR investigators may have interests that fall outside of the realm of NABIR (*e.g.*, in organic contaminants). As with all the *in situ* FRC research projects being conducted by NABIR investigators, the FRC Manager and the FRRP will review the extent to which *in situ* research by non-NABIR investigators might interfere with *in situ* research by NABIR investigators. This information will be provided to the NABIR Field Activities Manager at DOE for resolution with DOE program managers for EMSP and GTL.

- **Set up coordination and integration mechanisms at the second FRC.** As field plots are made available for *in situ* research for NABIR and other investigators by the second FRC, there will be a need to establish: a) quarterly conference calls between the NABIR Field Activities Manager, the FRC Manager, the FRC Science Advisor

and the FRRP to ensure coordination and integration, b) a FRRP review process for work plans and site characterization activities and c) a review and analysis process by the Science Advisor for the second FRC to ensure integration and coordination.

- **Continue to seek opportunities to coordinate and enhance links with such non-DOE federal programs and agencies as SERDP, NSF, EPA and USGS.**

3.3.3 Long-Term Integration Tasks (7-10 Years)

The following tasks will be accomplished over the long-term:

- **Develop communication linkages between the two FRCs through the establishment of a network system.** Telecommunications linkages between FRC sites, similar to those among the National Science Foundations' Long-Term Ecology Research (LTER) sites, will need to be established. These linkages will be extremely important for sharing data and computational tools, as well as for achieving other communication objectives. Further, to promote coordination of research and results among FRC Managers, their Science Advisors and the NABIR Field Activities Manager, an FRC Leadership Council may be established.

- **Promote the integration of data and research results across programs, particularly for issues of importance to Long-Term Stewardship (LTS).** This will be the responsibility of all the NABIR Program Managers, the FRC Manager, and the FRC Science Advisor. Of particular importance will be findings relevant to the fate and transport of mixed contaminant plumes. Tthe NABIR Field Activities Manager and the FRC Managers will coordinate and communicate with the DOE Office of Legacy Management and with EM, with the aim of facilitating the transfer of information and techniques for use at DOE sites. Furthermore, coordination and communication efforts will provide scientific information relevant to regulatory entities and other EM needs. For example, documentation of the effectiveness and time frame over which natural attenuation and/or enhanced bioremediation immobilizes or reduces subsurface contaminants in specific environments will be provided to parties involved with the regulatory process. See Section 3.4 for a discussion of technology transfer meetings.

- **Continue to seek opportunities to coordinate and enhance links with such non-DOE federal programs and agencies as SERDP, NSF, EPA, and USGS.** In addition, DOE and the FRC will seek international linkages with sites of DOE interest in countries such as Russia, Poland, Argentina, Canada and others as appropriate.

3.4 Goal 4 - Educating Students and Providing Scientific Data and Research Findings

The fourth goal for the FRCs combines the need for the FRC to: a) provide educational opportunities for students and b) disseminate collective characterization data and research

findings to end users, regulators, the scientific community, and other stakeholders.* Although these activities could be listed under the core activities for the FRC Manager, some detail on the scope of these activities is needed, and both activities will require inputs from many of the tasks in this Strategic Plan. For example, educating students will require: a) involving them in some of the field plot development tasks under goal 1, b) guiding them to understand the complex scientific issues associated with *in situ* bioremediation (goal 2) and c) introducing them to scientists from other institutions who may be funded by other programs, but who are conducting related research (goal 3).

Specific activities associated with this goal include:

- **Provide educational opportunities to students throughout the lifetime of the FRCs.** A ten-week field research practicum for students will be established in the short-term, and will continue for the duration of FRC activities. Practicums will enable students to work with NABIR FRC investigators in the field and to learn about subsurface field research. Because FRC sample collection activities occur year-round, student participation need not be limited to the summer. NABIR investigators will also be encouraged to consider sabbatical leave at the FRC. With the establishment of a second FRC and the use of FRCs by EMSP and GTL investigators, the number and types of educational opportunities may expand.

- **Communicate on a regular basis with the scientific community, regulators, end-users, other stakeholders, and the media.** The Oak Ridge FRC has developed a communication document entitled *Communication Strategy for the U.S. Department of Energy Natural and Accelerated Bioremediation Research (NABIR) Field Research Center (FRC)*. This document is available on the web at http://public.ornl.gov/nabirfrc/communicationStrategy.pdf. The Oak Ridge FRC communication strategy specifies several objectives and, after considering the target audiences, potentially effective methods for achieving those objectives. Among the methods outlined are those for sharing information within the scientific community, including: a) maintaining an FRC web site, b) hosting on-site workshops and meetings, c) providing investigators with a periodic newsletter and d) maintaining a library of journal publications. Formal and informal modes of communication with regulators are outlined in the Oak Ridge FRC Communication Strategy and these are expected: a) to keep the regulators apprised of FRC activities, b) to allow the FRC Managers to respond appropriately to the concerns and issues raised by regulators and c) to potentially resolve regulatory problems before they escalate. Similarly, different communication methods are outlined for use in achieving objectives relevant to other stakeholders, including the need to translate the results of FRC research to DOE sites as well as to support the regulatory decision process. A similar communication strategy will be developed and implemented at the second FRC in the middle term.

*Rather than rely merely on peer-reviewed publications by individual scientists for all information concerning the FRC field sites, the FRC will periodically pull together data and research findings into collective reports for posting on the FRC web site.

- **Hold periodic technology transfer meetings with DOE site end users.** Beginning in the middle term, the NABIR Field Activities Manager will work with the FRC Managers to have one of the FRCs host a periodic (every 2-3 years) meeting between scientists conducting research at the FRCs and DOE site end users to encourage knowledge and technology transfer. In preparation for these periodic meetings, the FRC Science Advisor, with support from the FRC Manager, will develop criteria or a decision tree for deciding whether *in situ* bioremediation would be suitable for a given DOE site. The criteria would be based on field or lab measurements or on specific experiments and *in situ* research results from the FRCs. In addition, the FRC Science Advisor would use outputs from the conceptual model to attempt to assess whether scale up issues would become problematic for DOE site end users.

- **Hold an annual investigators meeting at the FRCs.** Each FRC Manager will work with their corresponding FRC Science Advisor and with the NABIR Field Activities Manager to develop an annual meeting for NABIR and other investigators. The Oak Ridge FRC has been holding these annual meetings since opening (see http://public.ornl.gov/nabirfrc/Meetings.cfm/), and the workshop format for the second FRC likely will be similar.

- **Transfer research findings from NABIR, EMSP and GTL studies to DOE site end-users and others.** ERSD program managers and NABIR scientists will continue to work closely with EM and Office of Legacy Management colleagues in DOE headquarters to identify potential customers for transferring NABIR fundamental research to applied research and technology development, and to foster communication about scientific results to key end-users at other DOE sites. EM has been actively involved in providing input to the NABIR program through participation in panels, reviews and site visits. These interactions will continue.

Appendix I – FRC Strategic Plan over Time: An Overview

Short-term (1–3 years)	Middle-term (4–6 years)	Long-term (7–10 years)
Goal 1: Operate FRCs effectively		
Oak Ridge FRC		
Implement core activities	Implement core activities	Implement core activities
Identify and characterize new field plots	Expand field plots and continue characterization	Expand field plots and continue characterization
Open site to other BER investigators		
Second FRC		
Identify/establish second FRC and identify Manager and Science Advisor	Develop and characterize field plots; begin *in situ* studies	Expand field plots and continue site operations
Goal 2: Advance scientific understanding and analytical and predictive capabilities		
Investigate Processes Affecting *In Situ* Bioremediation and Contaminant Fate & Transport		
Achieve metals and radionuclide immobilization *in situ*	Understand processes that promote/inhibit bioremediation of metals and rads.	Develop understanding of *in situ* bioremediation in the context of mixed contaminant situations
Characterize field plot heterogeneity and conduct *in situ* research within plume boundaries (meter-scale)	Focus *in situ* research on tens-of-meters scale at the Oak Ridge FRC and meters scale at the second FRC	Focus studies on plume scale at the Oak Ridge FRC and tens-of-meters scale at the second FRC
Develop a conceptual model for the Oak Ridge FRC	Refine Oak Ridge conceptual model, and develop model for second FRC	Develop predictive capabilities and visualization and modeling interfaces
Goal 3: Coordinate and integrate within NABIR and with other programs		
Coordinate NABIR work at FRCs and Between FRCs		
Continue quarterly conference calls, and FRRP review of work plans at Oak Ridge FRC	Establish process for conference calls, FRRP review and integration of PI studies at second FRC	Establish telecommunication linkages between FRCs
Coordinate/ establish working groups	Coordinate between FRCs and integrate UMTRA results	
Integrate findings from UMTRA sites	Establish leadership counsel to coordinate activities at multiple FRCs	
Coordinate and Integrate NABIR and non-NABIR Studies and Results		
Open Oak Ridge FRC to non-NABIR studies (e.g., GTL, EMSP)	Promote integration between NABIR and non-NABIR studies	
Coordinate with SERDP, NSF, EPA, USGS and others		
		Establish international linkages
Goal 4: Educate students and provide scientific data and research findings		
Communicate with Different Target Audiences		
Host annual PI Meetings	Host annual PI Meetings	Host annual PI Meetings
Implement communication strategy at the Oak Ridge FRC	Implement communication strategy at the second FRC	
Transfer NABIR results to EM and DOE sites	Transfer NABIR, EMSP, GTL results to EM and DOE sites	
Establish educational opportunities at the Oak Ridge FRC	Establish educational opportunities at the second FRC and expand educational activities at the Oak Ridge FRC	

Appendix II - Potential FRC Research Topics

Examples of research intended to resolve the short-term task that demonstrates metals and radionuclide immobilization in the field at the Oak Ridge FRC:

- Research on the influence of hydrologic and physical attributes such as preferential flow and contaminant diffusion to and from the matrix on the microbially mediated reduction or precipitation of contaminants.
- Investigations that determine whether the delivery of electron donor and nutrients can be achieved in a spatially heterogeneous environment to enable efficient immobilization of contaminants.
- Research on the influence of sorption and oxidation on the rate and extent of contaminant bioreduction, and to what extent subsurface mineral oxides compete with terminal electron acceptors relative to the contaminants.
- Studies to determine whether the activity of metal-reducing bacteria in ground water can be sustained to effectively stimulate the reduction and immobilization of redox-sensitive metals and radionuclides.
- Investigations that focus on the natural attenuation of contaminants through microbial, geochemical or physical processes that are relevant to high recharge regions.
- Research that examines the rates and mechanisms of colloid-assisted contaminant transport, especially in systems that experience significant storm infiltration or are characterized by karst.

Examples of research intended to resolve the middle-term task that provides an improved understanding of the processes that promote or inhibit *in situ* bioremediation of metals and radionuclides at the Oak Ridge FRC:

- Investigations that provide new insights into the magnitude and extent of high risk/high flux subsurface discharge pathways.
- Studies that reveal the significance of transient preferential flow on the dissemination of subsurface contaminants at a variety of scales in high recharge systems.
- Research that defines the extent to which storm events contribute to lateral versus vertical contaminant flux.
- Scientific investigations on the spatial and temporal distribution of contaminants in structured media.
- Efforts to unravel the extent and magnitude of solid-phase contaminant plume buffering along discharge pathways.
- Investigations on the influence of low molecular-weight organic acids on metal or radionuclide geochemistry.
- Research that documents the conditions that accelerate or impede charge transfer reactions involving redox-sensitive species.
- Studies on the impact of seasonal shifts in the capillary fringe on the interactions among physical, chemical, and microbial soil components.

Examples of research intended to resolve the long-term task that provides an enhanced understanding of the strengths and limitations of microbially-mediated

subsurface metal and radionuclide remediation in mixed contaminant situations at the Oak Ridge FRC:

- Research that provides improved techniques for rapidly defining below-ground contaminant inventories and the extent of plume migration in structured media where high recharge rates have disseminated contaminants across vast subsurface domains.
- Investigations that provide techniques for rapidly characterizing shifts in microbial community structure and activity during remediation of contaminated sites.
- Techniques, such as neutron scattering and x-ray tomography, to characterize the pore structure and aggregation state of structured soils for the purpose of scaling contaminant bioremediation processes.
- Applications for credible multi-process, multi-permeability, hydrobiogeochemical transport models for simulating contaminant bioremediation and fate and transport in heterogeneous structured soils.
- Studies that provide model validation using coupled high-performance computing with multi-scale experimental datasets involving *in situ* bioremediation and contaminant fate and transport.